

DETECTION OF TEMPER EMBRITTLEMENT IN STEEL

BY MAGNETOACOUSTIC EMSSION TECHNIQUE

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INTRODUCTION

A bulk ferromagnet possesses two types of domain walls: 180° and non- 180° [1]. In the case of iron-like ferromagnets, the latter type of walls are 90° domain walls. As a result of the magnetoelastic interaction, unit cells of a ferromagnet deform slightly in a way that is unique to particular types of domains [2]. Such a spontaneous deformation, called magnetostriction, causes local lattice strains at domain walls with the strain fields being particularly strong for 90° domain walls [3]. The motion of the 90° domain walls is followed by a redistribution of local lattice strain fields. Elastic energy is being released by this process and propagates through material as acoustic waves. Acoustic emission (AE) generated due to magnetic domain wall motion is thus defined as magnetoacoustic emission (MAE).

Magnetic domain walls and lattice defects "see" each other through the local strains that they create, so the domain wall defect interaction is much stronger for 90° domain walls. In the course of external field-induced motion, 90° walls encounter strong resistance by defects. The presence of these defects, hence, creates effective potential barriers against 90° domain wall motion [4,5]. During this process of domain wall motion, 90° walls are stalled at the defect sites and, with a higher driving force, execute abrupt jumps over the barrier. A sudden AE burst is produced by such discrete 90° wall motions.

During the thermally activated diffusional motions at elevated temperatures, impurity atoms of certain alloys are trapped and accumulated at grain boundaries causing significant reductions in the impact strength of the material. For ferromagnets, these impurities further strengthen the potential barriers at the grain boundaries resisting the motion of 90° domain walls and the MAE characteristics of such materials should be related to the degree of temper embrittlement.

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Our initial study of NDE temper embrittlement detection was performed for HY80 steel samples employing a statistical method to analyze the MAE spectra produced by the application of an AC magnetic field to the samples [6]. In this study the MAE signal amplitudes were detected in a 10 microsecond time-window positioned at the peaks of the MAE bursts. These MAE amplitudes were then processed for pulse height distribution analysis. The resulting histograms were fitted to the Gaussian distribution function and the results showed a good correlation to the impact strength of these samples.

Several questions arose from the previous results; for example, only one MAE peak was observed in a period corresponding to a half cycle of the hysteresis loop centered at the coercive field point, whereas two peaks were expected. The purpose of the present study is to resolve this discrepancy and to provide a deeper insight into the basic characteristics of MAE related to various material properties. For this, improvements were made in the MAE instrumentation to provide some added control over the experimental conditions.

EXPERIMENT

A detailed description of the HY80 steel samples, magnetizing units and AE detection system can be found in Ref.1 and will not be repeated here. The experimental setup, however, has been modified to vary the AC external magnetic field frequency and to adjust the functional form of the applied field, $H(t)$, such that the pickup coil output, $e(t)$, can be obtained close to a desired shape. This was possible by using the feedback circuit shown in Fig. 1. Use of the feedback circuit, however, limited MAE generation and was employed only in certain cases.

Among the six HY80 steel samples, two samples were used mainly for the present experiment. These are untreated (unembrittled) and heat treated for 50 hours (embrittled) samples.

A waveform digitizer was used to record the MAE signal. Histograms of the MAE signal could be constructed directly by using a multichannel analyzer, or numerically from the data stored in the digitizer.

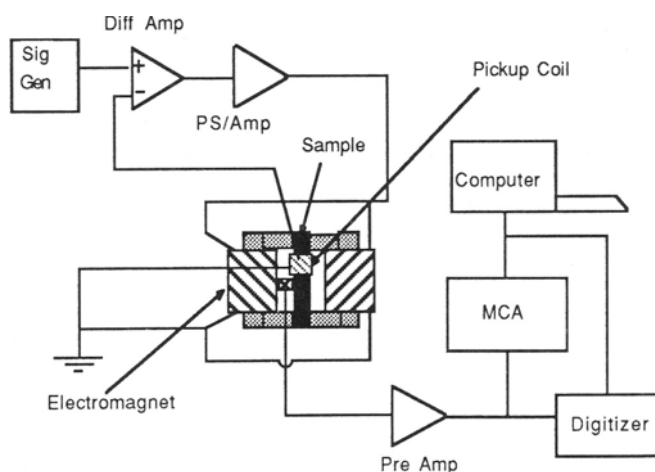


Fig. 1. Block diagram of the MAE setup including magnetizing unit, AE detection circuits and data acquisition system.

RESULTS AND DISCUSSION

Fig. 2 shows the MAE spectrum and waveform of $e(t)$ obtained for an unembrittled HY80 steel sample at the 60 Hz AC field frequency. An approximately sinusoidal form of $e(t)$ was obtained without using the feedback circuit. The waveform of magnetic induction, $B(t)$, should be similar to that of $e(t)$ except it is phase-shifted by 90° . The period of $e(t)$ corresponds to a complete sweep over the hysteresis loop. The major irreversible domain wall motions occur just before and after $B=0$. This means that two MAE peaks should be observed in each one-half cycle of the hysteresis loop. The MAE spectrum in Fig. 2 shows apparently a single peak which slightly lags in time behind the peak of $e(t)$. The slight phase lag of the MAE peak with respect to that of $e(t)$ is believed to be due to the delayed motion.

Fig. 3 shows the results obtained for the embrittled sample under the same conditions as in Fig. 2. At almost the same peak amplitude of $e(t)$, the MAE peaks in this sample are distinctly larger than that of the unembrittled sample. Such a difference in MAE peak amplitudes is apparently consistent with the original assumption of enhanced effective potential barriers in embrittled samples due to accumulations of impurities at the grain boundaries.

Fig. 4 shows the waveforms of the MAE spectrum and $e(t)$ obtained for the unembrittled sample at .7 Hz of AC field frequency using the feedback circuit. The MAE envelope begins to spread as seen in the figure. It is shown in the next figure that an increase in the AC magnetic field intensity produces the complete two-peak structure of the MAE spectrum in a half cycle of the hysteresis loop. It is clear that the results in Fig. 3 were obtained by sweeping over a minor hysteresis loop reaching only the lower portion of the irreversible domain wall motion region.

A clear double-peak structure of MAE bursts is obtained when the AC field intensity is increased at .7 Hz as shown in Fig. 5. The lack of a double-peak MAE pattern at 60 Hz can now be explained easily. Due to the strong interaction of 90° domain walls with defects, these walls are pinned during their motion. Since they are coupled with relatively

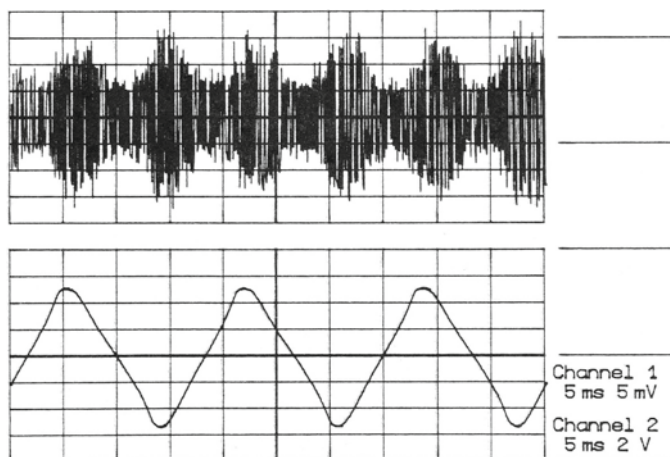


Fig. 2. MAE spectrum obtained for the unembrittled HY80 steel sample at the 60 Hz AC magnetic field frequency.

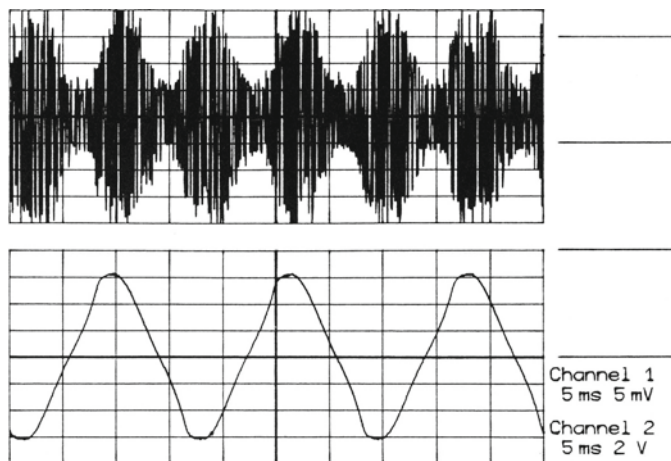


Fig. 3. Results for the embrittled sample obtained at 60 Hz. The peak MAE amplitude in this sample is considerably higher than that of the unembrittled sample at the same level of $B(t)$.

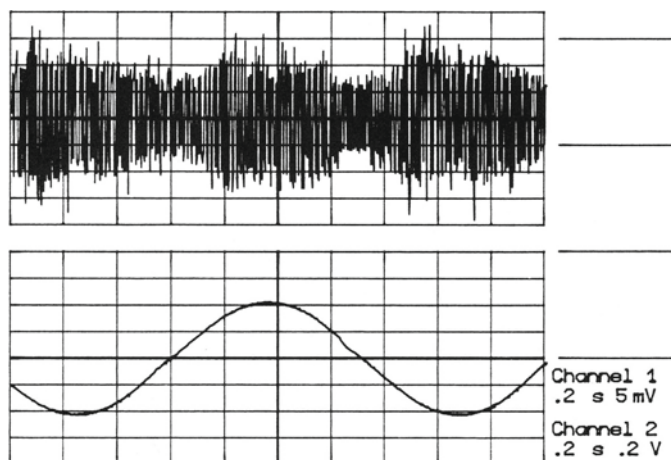


Fig. 4. Results for the unembrittled sample obtained at .7 Hz showing a spread of MAE peaks.

resistance-free 180° walls, 90° walls are bent at the defect sites. At a higher frequency, fast moving 180° walls enhance the motion of 90° walls after they are freed from the defects. Hence the 90° walls spend less time in between the two major potential barriers they encounter before and after passing the point where $B=0$.

The results of the same measurements for the embrittled sample are shown in Fig. 6. The MAE pattern in this figure is seen to be asymmetric and its amplitude is not any higher than that shown in Fig. 5, for the same shape of $e(t)$. There are two possible reasons for such an asymmetry in the MAE pattern. First, if the sample was not sufficiently demagnetized before the AC field application, the actual hysteresis loop could have been shifted above the horizontal axis of the B - H coordinate. Second, with the sample being embrittled, the intensity of the AC field may not be sufficient enough to drive certain portions of 90° walls over some unusually strong

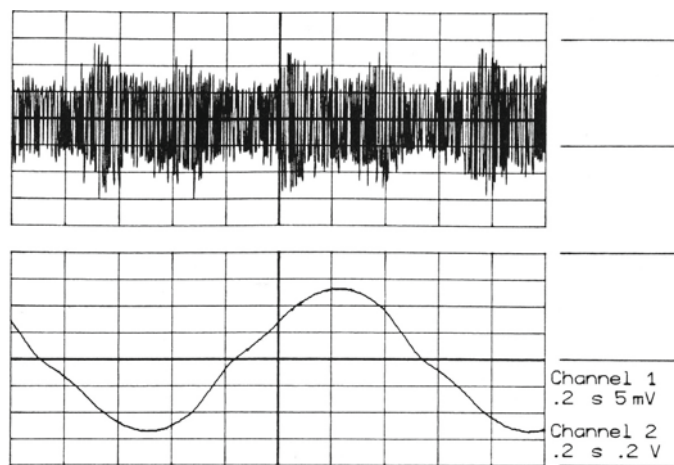


Fig. 5. Results of repeating the measurements of Fig. 4 with an increased AC magnetic field intensity showing two peaks of MAE in one-half cycle of the hysteresis loop.

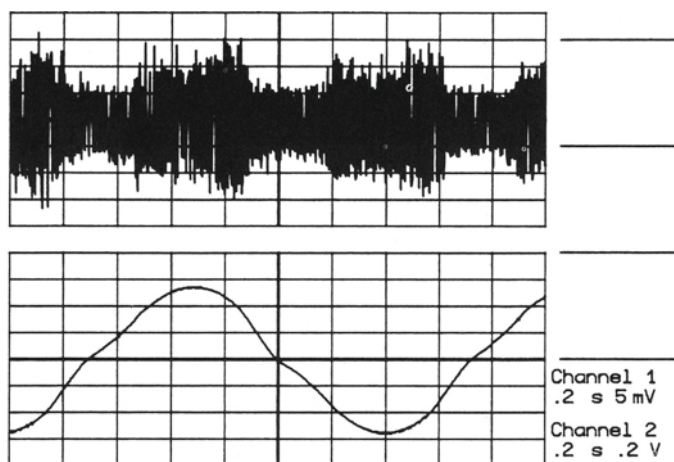


Fig. 6. Results of the same measurements as in Fig. 5 for the embrittled sample showing an asymmetric MAE burst in one-half cycle of the hysteresis loop.

potential barriers. The 90° wall motions under such a condition will certainly contribute to the asymmetry in the overall pattern of the MAE spectrum. Even though the first speculation is thought to be unlikely, it cannot be excluded since the measurement procedure did not exactly insure that the initial phase of the AC field was zero. Since the asymmetry in the MAE burst was observed in the embrittled sample only, it is more likely that the main effect is due to the severe potential barriers at the grain boundaries where the impurities are trapped and accumulated. This means that a symmetric MAE pattern should be obtained by the application of a much stronger AC field.

The results of pulse height distribution analysis performed by using a multichannel analyzer showed some very interesting characteristics in the histograms obtained for unembrittled and embrittled samples. The measurements, however, have not been repeated and the presentation of the

results will be deferred until complete reproducibility has been confirmed.

SUMMARY AND FURTHER DISCUSSION

The phase lag of the MAE peaks behind that of the induction pickup coil output observed at the 60 Hz AC field frequency implies strongly that the 90° wall-defect interaction is mainly responsible for the generation of MAE. The difference in the peak MAE amplitudes between the unembrittled and embrittled samples provides the evidence of strengthened potential barriers resisting 90° domain wall motions at the grain boundaries of the embrittled sample. The presence of an asymmetric MAE pattern observed only in the embrittled sample also supports the idea of stronger potential barriers as the material becomes embrittled. To provide complete validity of this fact, the recovery of a symmetric MAE pattern in embrittled samples should be confirmed by applying a stronger AC magnetic field.

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